Power Transformers For Radio

LESSON ND-19

SPRAYBERRY ACADEMY of RADIO

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POWER TRANSFORMERS FOR RADIO

LESSON ND-19

In 1831, Michael Faraday announced the discovery of electromagnetic induction. He found that a wire carrying current would, when wrapped around a piece of iron, magnetize the iron. For a long time his discovery was merely a laboratory experiment. Then in England, in 1882, Gaullard and Gibbs patented a system of alternating current distribution using transformers. Further developments have led to its use so universally that without transformers, many of today's modern conveniences would not exist.

In your previous SAR lessons, you have covered many of the principles of A.C. and electromagnetism. These have not, until now, been presented as a unit in their relation to transformers. This lesson will enable you to understand these principles as they are applied to this most useful device.

While a transformer is one of the *important* units used in radio, it may become a lethal instrument if improperly handled. Here, as in other cases, *ignorance excuses no one.* Always remember that by the time a person finds out how much *shock* he can stand, he will *probably be too far gone* for medical help to aid. A good rule to follow is to never expose yourself to the *high voltage* (above 25 volts) termnials of any type of transformer.

Radio receivers, amplifiers and special electronic apparatus require power in many different values than that which may be usually obtained from the common sources. In the majority of cases, this power will be obtained from a *power unit* which will supply the apparatus with the correct *form* of power but which draws its power from the commercial supply lines. There are many cases, however, where it would be either impractical or impossible to use commercial power lines. Automobile radios, aviation communication, farmers and others beyond the reach of power lines must depend on other devices.

Special cases require the use of batteries. These are expensive and often of a size as to be very inconvenient. Batteries must either be charged or replaced, and for these reasons other power sources are often more desirable. A device which converts available power into the form required by electronic apparatus is called a power pack or power unit. These may be classified as follows:

A. Direct Current Power Units.

B. Alternating Current Power Units.

C. Combination A.C.-D.C. Power Units.

Under those classified as D.C. power units are those drawing their power from 6, 12, 28, 32, 110 and 220 volt D.C. sources. Those operating from 6 and 32 volt sources generally derive their pow-

er from storage batteries, while those operating from 110 and 220 volts generally draw from commercial power lines supplying direct current. Many areas of large cities, farms, mining camps and oil company locations use 110 or 220 volt D. C. distribution systems. Automotive, aviation and many farm receivers are operated from 6, 12, 28 and 32 volt batteries. In many of these cases, you will find that the high voltage required for a receiver is derived from a small motor generator, a filter and a voltage divider, while the low voltage filament or heater supply may come direct from the battery or source. It is more often found, however, that the D. C. supply is used to operate a *vibrator* which interrupts or, in some cases, reverses the supply voltage. This interrupted or reversing D.C. will be applied to a transformer primary winding where it will be increased or *stepped up* in voltage and then rectified and filtered.

Equipment designed to operate from 110 or 220 volt D.C. supplies will not usually incorporate the use of transformer, and, therefore, need not be considered at this time. Combination A.C.-D.C. receivers do not require the use of power transformers.

By far the most readily available and most used power sources all over the world are the commercial supply lines. This, of course, has made popular the use of A.C. power units, and, since they require the use of power transformers in conjunction with rectifiers, filters and voltage dividers, it is well that you take up the study of power transformers. It is the purpose of this lesson to thoroughly acquaint you with the theory, construction, operation and regulation of power transformers as used in power units for electronic apparatus. These operate from various frequencies depending upon the frequency supplied from the commercial lines. In the U. S., frequencies of 25, 40, 50 and 60 cycles are used with 60 cycles being the most used and considered standard. These power line frequencies and those of 80 and 120 cycles are occasionally found in other countries.

The 60 cycle frequency is the most popular because, since time is a factor of frequency and since time is divided into 60 seconds per minute and 60 minutes per hour, it is convenient. This is true due to the fact that all A.C. calculations involve the use of time as a factor. It will become evident as you progress with this lesson that transformers, as well as other power unit components, *must be used only with the frequency and voltage for which they are designed.*

A TYPICAL POWER TRANSFORMER

In Fig. 1, a typical electrical diagram of a power transformer and several related devices are shown. The heavy vertical lines are used to indicate the metal core of magnetic material. Though a metal core is illustrated in this manner, it *should not* be assumed to have this actual shape. It could be any one of several physical forms to be described. The wire windings are shown with their terminals connected to binding posts 1 to 16, and each individual winding is des-

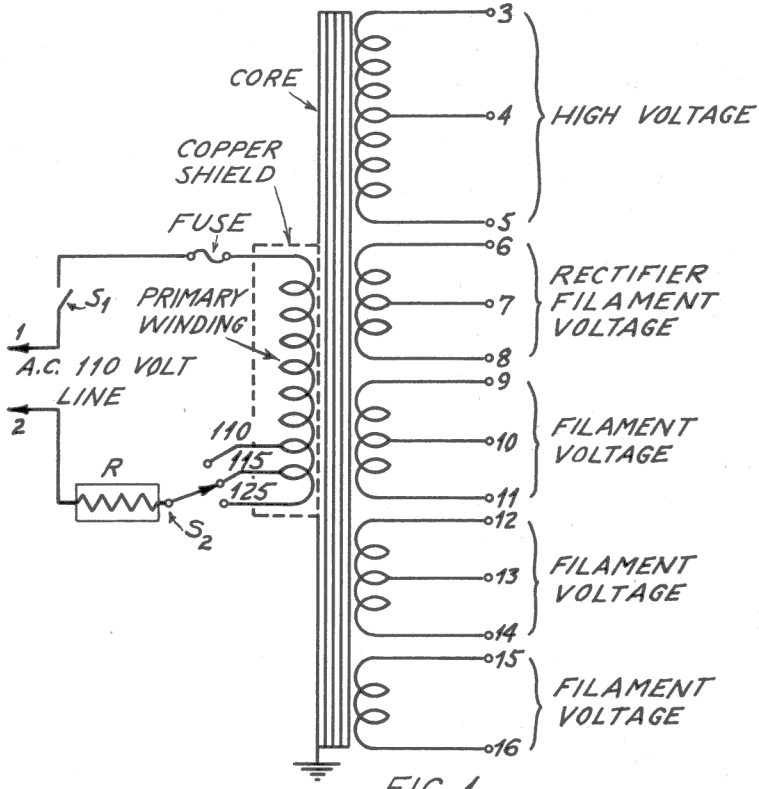


FIG. 1

ignated as to its purpose. In *series* with the primary are shown two switches S_1 and S_2, a fuse and a resistor R. The switch S_1 is the *off* and *on* control. Switch S_2 is for the purpose of matching the primary to different line voltages. This is a necessary precaution because line voltages vary in different locations. Even though the commercial line is adjusted at the power house to a certain voltage, the voltage will vary along the line as the distance or load varies. IR losses in the line and the amount of equipment connected to the line which affect power factor and load are the main reasons for this variation. Later in this lesson you will learn how a non corrected line voltage can *damage* or *impair* the operation of apparatus. The resistor R is a *ballast* or control resistor, and its function in conjunction with a transformer will also be described later in this lesson. While Fig. 1 shows an input of 110 volts and though many persons refer to the commercial lines as a 110 volt source, do not assume that this figure is always correct due to the reasons as outlined.

A fuse is shown because the primary is wound with a certain size wire. This wire will carry only a certain amount of current without *burning out*. The fuse will be so chosen that it will burn out (in case of an overload) before the primary wire melts. An overload

or short circuit placed on the secondaries will cause an abnormal current to flow in the primary, and this current will heat the primary due to the IR drop and loss in the wire. This loss will be dissipated in the form of heat which would melt the primary wire thus *opening* the winding. No current could then flow.

Around the primary winding and between it and the secondary windings is shown (by the dotted line in Fig. 1) an electrostatic shield. This is usually a strip of copper screen placed about the primary winding but arranged so that its ends do not touch each other. The screen is also insulated from all other parts of the transformer; note, however, that it is grounded. This screen's purpose is to isolate in the primary winding, any spurious and unwanted parasitic impulses which might come into the power unit via the power supply lines. These parasitic noises are *thumps* from neon signs, vacuum sweepers and mixers, etc. The shield acts as a third plate of a condenser, thus creating a *series* of two capacities. This brings about a consequent reduction in the total capacity of the two effective series condensers. In the transformer, the windings possess a certain amount of *electrostatic* influence on one another; hence, when the screen is placed between them, it serves to reduce their *capacity* coupling, and by its effect reduces the amount of electrostatic coupling between the primary and secondary. By connecting the screen to ground, a portion of any spurious impulses will be diverted to ground and thus be kept out of the apparatus supplied by the power unit.

The various secondaries shown in Fig. 1 are designated as to their supply function. Because it supplies the *high* voltage to the rectifier, the winding connected to terminals 3, 4, 5 is termed the high voltage winding. As you have learned, most rectifiers require a source of power to heat their cathodes or filaments. This power will be supplied by the winding so designated and connected to terminals 6, 7, 8. The other secondary windings would be used to supply the cathode or filament of the RF, detector and AF stages of a receiver. Shown connected to terminals 4, 7, 10 and 13 are the *centertaps* of the respective windings. The purpose of centertaps for transformers has been explained in a previous lesson.

Now that you have been introduced to the elements of a power transformer, you are ready to consider the factors which influence the choice or design of a power transformer for a particular purpose.

CONSIDERATIONS GOVERNING TRANSFORMER CHOICE

While a radio man will rarely design and build a transformer, he may often be faced with the choice of several types in making replacements. In order to present the fundamental elements of good design to help you make correct replacements, it will be necessary to explain in detail the features of good transformers. For this reason, the components of a power transformer will be explained

much as though you were going to design one.

The first thing to have in mind when choosing a transformer for a particular job is the amount of power it must distribute. A good principle for you to keep in mind is that it is good practice to figure transformer components large enough to handle 100% more than the actual power demand. For example if a secondary is to supply a current of 5 amperes, a size of wire winding should be chosen which will carry 10 amperes. By ascertaining the load to be carried by each individual secondary and adding their values, the amount of power that the primary must handle can be obtained. To this amount must be added the percentage lost as heat in the particular type of core to be used. This percentage may range from 2% to 5%.

The second consideration should be the choice of the wire turns ratio. The voltage induced in a secondary winding depends on the ratio of the number of wire turns on the primary to the number of wire turns on the secondary. For example, if the secondary has ½ as many turns as the primary, then the secondary voltage would be ½ of the primary voltage. If the number of turns in the secondary is ten times the number in the primary, the secondary voltage will be ten times the primary voltage.

This ratio holds true for any combination of turns between primary and secondary. If there is more than one secondary, this ratio holds for each secondary individually.

In practice, it is usual to express the voltage of wire windings in a transformer as *volts per turn.* Suppose a transformer operates from a 110 volt source, and its primary winding contains 100 turns. The volts per turn, in this case, are equal to $\frac{110}{100} = 1.1$ volts per turn. If the secondary of this transformer consists of 50 turns its voltage would equal 50×1.1 or 55 volts. Likewise, if the secondary has 300 turns its voltage will equal 300×1.1 or 330 volts.

It is important, as mentioned before, that you remember *each secondary may be considered as a separate unit, and a principle that applies to one secondary will apply to all of those on the same transformer.* The relation between primary and secondary may be expressed as follows:

Formula No. 1 $\quad \frac{Ep}{Np} = \frac{Es}{Ns}$

Formula No. 2 $\quad \frac{Ep}{Es} = \frac{Np}{Ns}$

Where:
Ep = Primary voltage
Es = Secondary Voltage
Np = Number of primary turns
Ns = Number of secondary turns

The secondary voltage may be found by using the following:

Formula No. 3 $\quad Es = Ep \times \frac{Ns}{Np}$

LINE VOLTAGE

A variation in the line voltage or in the number of wire turns of the primary will affect the secondary voltage. As an example of the way the secondary voltage is affected by an increase in line voltage, suppose the primary contains 200 turns and the line voltage is 110 volts. Suppose, too, that a sec-

ondary winding is to deliver 2.5 volts to operate the heater of a 2.5 volt tube. Using formula No. 2, note that $\frac{Ep}{Es} = \frac{Np}{Ns}$ Next substitute for the voltage and the number of primary turns as follows:

$$\frac{110}{2.5} = \frac{200}{Ns}$$

Division of the left hand side of the equation gives 44. Therefore, the equation now reads

$$44 = \frac{200}{Ns}$$

This, in turn, is equal to

$$\frac{200}{44} = 4.54.$$

Thus, there are 4.54 turns for the secondary. If this transformer were connected to a 125 volt power line, the results would be:

$$Es = 125 \times \frac{4.54}{200} = 2.83 \text{ volts.}$$

This is an increase of 13.2% in heater voltage. It has been found, in practice, that the life of a heater, operated at 10% increase above rated voltage, will be shortened by about half; thus, the operating conditions in the foregoing example would materially shorten the life of the tube.

Radio manufacturers do not, as a rule, know what voltages will be available in the section of the country where the receiver is to be used. Therefore, it is customary, in many radio sets, to use a switch, S_2, as shown in Fig. 1. When the receiver is installed, the radio man should check the line voltage (with a voltmeter) and adjust the switch to the position which is nearest to the value of the line voltage. Automatic methods of compensation for line voltage will be discussed later on in this lesson.

The third consideration in good transformer design concerns the metal core. This, of course, involves magnetic principles—some of which you have not heretofore studied in your SAR course. It is not necessary for you to memorize the relation between the magnetic units to be described. However, you should study these principles in careful detail because you will need this knowledge in your radio work.

Refer to Fig. 2 and observe the direction of the magnetic lines of force. This figure illustrates a permanent magnet of the bar type. Notice that the lines of force leave the magnet at the *north* pole and enter at the *south pole.* Outside the magnet, the lines of force must travel through the surrounding air. Remember that the lines of force leave the N pole in all directions and enter the S pole from all directions. However, they are more dense, or closer together, *inside* the magnet than outside. Only a few lines of force are illustrated though, actually, many exist. All of the lines of force inside and outside of the bar magnet are called the *flux* of the magnet. The path through which this flux travels is called the magnetic path. The bar magnet shown in Fig. 2 has open ends so the longer part of the magnetic path is through air, you will readily see that if a complete *path through iron* is provided, a much stronger *concentration of flux* will exist and the magnet, as a whole, will be much stronger. In Fig. 3, the lines of force are confined al-

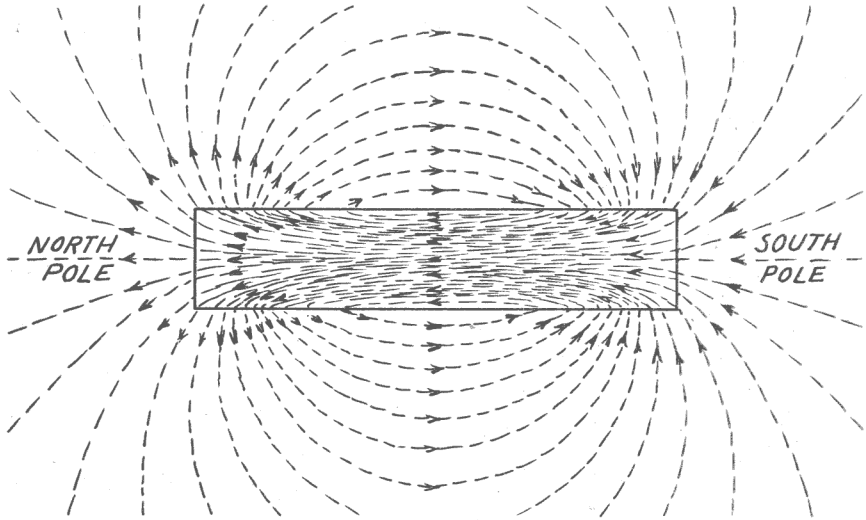


FIG. 2

most completely through iron. Iron, therefore, in this case, provides the principle magnetic path.

Figure 4 shows an electromagnet consisting of two windings on an iron ring. This iron ring provides the same kind of magnetic path as illustrated in Fig. 3. Note, however, that in Fig. 4, the path is circular. In Fig. 3, use is made of a *permanent* magnet. In Fig. 4, magnetism is only present when current flows through a winding—thus, the latter is an electromagnet.

The relationship of electrical current *flow* and the *movement* of magnetic lines of force, or flux, is very similar. Heat is produced by the continuous movement of either. In either case this heat can be controlled. In both, a force exists which causes a flow or condition of stress. *Electromotive* force causes current flow and *magnetomotive* force causes magnetic stress. Steady lines of force such as those produced by a steady flow of current in a coil or from a permanent magnet will not produce heat magnetically. It is only when the lines of force are changing or vary-

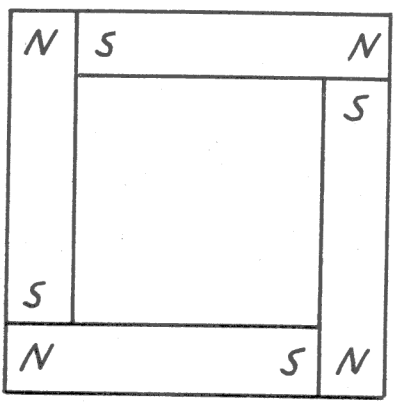


FIG. 3

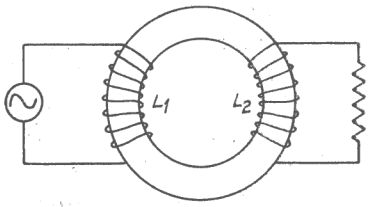


FIG. 4

ing that heat is produced by magnetism. Therefore, magnetism caused by unvarying direct current flow does not produce heat, but magnetism caused by *alternating current* or *pulsating direct current* does produce heat.

It is interesting to compare this similarity between the laws of electricity and those of magnetism. While they do not represent the same thing, they are related and analogous to each other.

IN ELECTRICITY

1. Electromotive force
2. Current
3. Resistance

IN MAGNETISM

1. Magnetomotive force
2. Lines of force (flux)
3. Reluctance

Each of the magnetic qualities are defined in certain units. The unit of magnetomotive force is the Gilbert. The name was chosen in honor of William Gilbert, an English Physicist.

The unit of flux is the Maxwell. This name, also, was in honor of another English Physicist, James C. Maxwell.

The unit of reluctance is the Oerted. This name honors Hans Christian Oersted, a Danish Physicist.

Gilberts may also be expressed as *ampere turns*—this latter term being most often used. The ampere turn value of a coil of wire is equal to the product of the number of turns and the value of the current in amperes. Thus, if 2 amperes flow through 150 turns of wire, the ampere turn value is equal to $2 \times 150 = 300$. One Gilbert is equal to .7958 ampere turns. The word turn as used here refers to a turn of wire around a form. This form is usually made of insulating material, and, in the case of power transformers for radio receivers, this form is usually around an iron core.

A Maxwell is equal to one line of force and is a very small quantity when compared to the actual number of lines of force about an electromagnet.

An Oersted is equal to the reluctance offered to the flow of flux through a 1 centimeter cube of air. In a magnetic circuit, reluctance is nothing more than the opposition offered to the presence of flux.

The relationship of magnetic units is similar to that of Ohm's law.

Thus, one Gilbert acting on a magnetic circuit having a reluctance of one Oersted will produce one Maxwell of flux.

To show the relationship between these units, the following formulas are used:

$$\text{Gilberts} = \text{Maxwells} \times \text{Oersteds}$$

$$\text{Maxwells} = \frac{\text{Gilberts}}{\text{Oersteds}}$$

$$\text{Oersteds} = \frac{\text{Gilberts}}{\text{Maxwells}}$$

Gilberts, Maxwells and Oersteds are all very difficult to measure practically, and this is rarely attempted except in the well equipped laboratory where everything necessary is available for this type of measurement.

The more practical way to work with these units in relation to power transformers is by calculations made with a core material having a fixed value. This value will be explained in this lesson, but it is

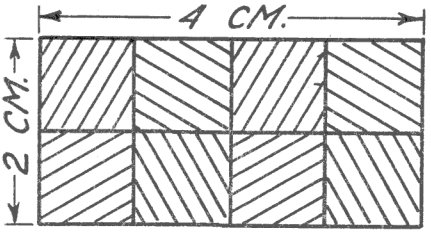


FIG. 5

necessary that you study other related units first.

FLUX DENSITY

For every *unit of area* (for instance, 1 square inch or 1 square centimeter) in a transformer core, so many lines of force will pass. This is the *flux density,* and the Greek letter Beta (*B*) is used to represent it in mathematical equations. Do not confuse the *flux density* with the total number of lines of force in a core. A study of Fig. 5 will make the difference between the two clear. In this core *cross section* each of the small squares represents one square centimeter—the total area being equal to 8 square centimeters of transformer core material. Suppose an electromagnet causes 16,000 lines of force to travel through the entire area of 8 square centimeters. This does not mean that 16,000 lines are going through each square centimeter in Fig. 5, but it does mean 16000/8 or 2000 lines per square centimeter. It has become standard practice in the radio field to state the number of lines per square centimeter. Thus, every one of the square centimeters in Fig. 5 may be assumed to pass 2000 lines force, and, in this example, the flux density is 2000 lines per square centimeter. If the total area shown in Fig. 5 represents the cross section of a transformer core, then the core would be said to have an area of 8 square centimeters. With this information, you may now understand the relation between the total flux, the flux density and the area of the core. This may be expressed as follows:

$$(1)\quad M = A \times B$$

$$(2)\quad A = \frac{M}{B}$$

$$(3)\quad B = \frac{M}{A}$$

Where:

M = Total flux in Maxwells

A = Cross section of core in square centimeters

B = Flux density or lines per square centimeter

The unit for flux density is the *Gauss*, so called to honor a mathematician, Karl F. Gauss, and, instead of saying the flux density is equal to so many lines of force, it is usual to state the density as being in so many gausses. *Always* remember, however, that this refers to *gausses per square centimeter.*

MAGNETOMOTIVE FORCE

Another very important magnetic quality which has been briefly mentioned is the *magnetizing force.* This is sometimes referred to as m.m.f. and is represented in mathematical problems by the Greek letter Eta (*H*). In relation to flux density, or *B*, the magnetizing energy, or *H*, is usually expressed in Gilberts per centimeter of length; length, in this case, represents the metal core length.

This core length means *the total distance that a line of force would*

have to travel to make a loop completely around from one pole of the magnet, out and through the conducting medium, air or core, and into the other pole and back to its starting place.

Occasionally the flux density may be expressed in lines per square inch. When this is done, the *H* is usually given in ampere turns per inch.

In most cases, *H* is given in ampere-turns, and this term is the most convenient to work with. If *H* is given in Gilberts, it may be changed to ampere-turns by dividing by 1.26 or multiplying by 0.795.

As has been stated, it is difficult to measure the total flux or the flux density. *For this reason, it is common practice to assume a flux density value.* This can only be approximated when a design engineer has experience in this work. For a given *grade* of core material, a design engineer can, by experimenting, soon learn what value to assume for that particular material. Other design answers can easily be obtained *once this value is known.*

For various power transformer requirements, a certain magnetomotive force, *H*, is needed to produce a flux density, *B*. Graphs or curves, called *BH* curves, are used when this information is wanted. The manufacturers of transformer core material know from laboratory work and experiments what the flux density of a certain core material will be. A flux density is assigned to various core materials, and from this information the design engineer can obtain data with which to design a transformer.

Figure 6 illustrates a typical set of *BH* curves. As may be seen, the graph is divided at the left into *Kilogausses*, and along the bottom into Gilberts per Cm or *H*. The characteristics of several materials are shown as curves. An example

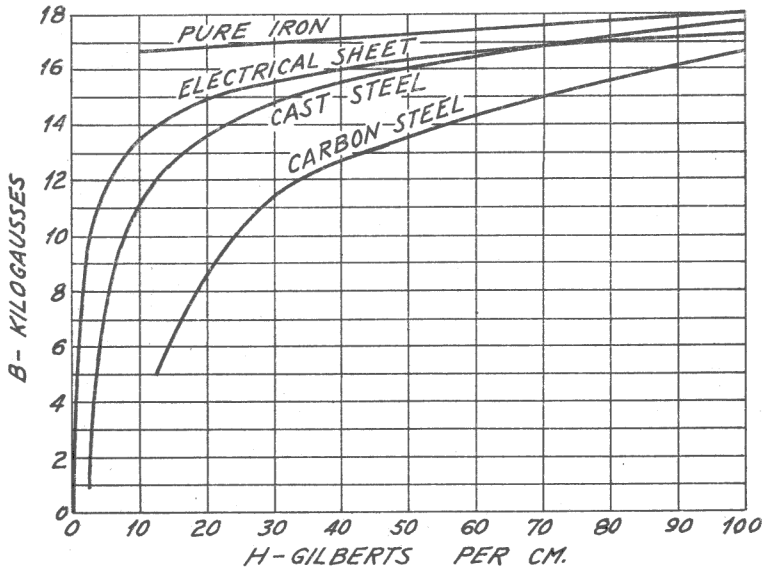


FIG. 6

will make the use of such a curve clear. A transformer is to be designed using *electric sheet* as core material with a cross section of 5 square centimeters. It is desigend to produce a flux density of 75,000 lines through the core which is to be 30 centimeters in length. The problem is to find how many ampere-turns will be required to produce a flux density of 75,000 lines. As you have already learned, $B = \frac{M}{A}$. Substituting for this problem gives $\frac{75{,}000}{5} = 15{,}000$ gausses or 15 kilogausses. By referring to Fig. 6, you may see that to magnetize this material (electric sheet) to a flux density of 15 kilogausses requires approximately 20 Gilberts per centimeter. 20×30 gives a total of 600 Gilberts. To change this to ampere-turns, merely multiply $600 \times .795$ which gives an answer of 477 ampere-turns. Once the ampere-turns are known, the actual number of turns for both primary and secondary windings can be figured. If some other core metal had been chosen, reference to the *BH* curve for the metal would allow the calculation as outlined.

Another calculation would be necessary to include the frequency for which this core is to be designed. The last mentioned formula does not take frequency into consideration.

A better formula for practical work is as follows:

$$\text{Turns-per-volt} = \frac{10^8}{BAf4.44}$$

Here *B* equals kilogausses per square centimeter. A equals core area in square centimeters, f equals frequency and 4.44 is a constant derived from the variations of induced voltage with changes in frequency.

It is customary to change the ampere-turn result to an even figure to enable the more accurate locating of centertaps on secondary windings.

PERMEABILITY

Iron, or an iron alloy, is a better conductor of flux than air, and this ability to provide a path for flux is termed the *permeability* (Mu) of the magnetic conductor. Permeability is the opposite of reluctance, just as conductance is the opposite of resistance. From this it is obvious that permeability is the reciprocal of reluctance (*R*) and can be written $\text{Mu} = \frac{1}{R}$. The permeability of a core metal may also be obtained from its *BH* curve because permeability is also equal to the ratio of *B* to *H*. Thus, if the *B* of a core metal in Fig. 6 is divided by the corresponding *H* value, the permeability value is obtained. For instance, it is seen for the cast steel curve in Fig. 6 that if *B* equals 11,000 Gausses, *H* will equal 10 Gilberts per centimeter. The permeability of this cast steel at 11,000 Gausses would be equal to $\frac{11{,}000}{10}$ or 1100.

Several other values may be calculated for the cast steel curve in Fig. 6, and from these values a curve could be laid out for the permeability which would indicate the correct value for the ranges shown. Such a curve is shown in Fig. 7 and is derived from the cast steel

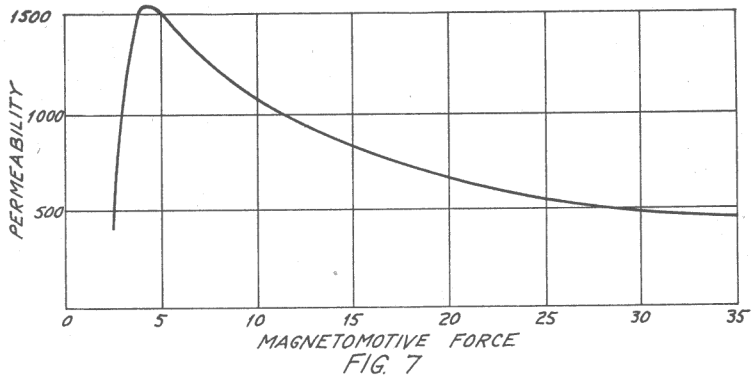


FIG. 7

curve of Fig. 6. This shows a static or D.C. permeability curve. When A.C. is applied, *H* is not constant, but it is varying, and for that reason the A.C. curve would not appear as in Fig. 7. This will be explained when the study of *Hysteresis is covered.* All *non-magnetic* metals have a permeability of very nearly 1. The *magnetic* metals have a permeability much greater than 1. Transformer engineers try to use core metals having high permeability, and though there may be many other metals more suitable than electric sheet steel, it is more universally used because of its lower cost. The following table will show the maximum permeability of various magnetic metals.

Metal	Maximum Mu
Annealed Cast Steel	14,800
Annealed Iron	14,400
Cast Steel	3,500
Electric Sheet Steel	3,270
Annealed Cast Iron	600
Cast Iron	240
Steeel Hardened	110
Tungsten Magnet Steel	105
Chrome Magnet Steel	94

The foregoing table is *not* arranged according to the *cost* of the materials but merely shows the relative maximum permeability of those listed. As already stated, the electric sheet or silicon steel is the most common material used for power transformer cores because of its fairly high permeability and low cost.

RELUCTANCE

Reluctance is that property of a magnetic circuit which determines the total magnetic flux in that circuit when a magnetomotive force is applied. It is analogous to the resistance of an electric circuit with the difference being that,in an electrical circuit, the resistance remains practically the same whereas in a magnetic circuit, the reluctance *changes* along with changes in flux density. This is important for you to remember because it has been the practice to reduce the mass of core metal to save weight, copper and expense. This is the reason for the very poor *regulation* of so many radio power transformers. One important factor in choosing a transformer is its weight for a heavier transformer will generally be better than one of less weight.

The reluctance value of a magnetic circuit may be easily calculated from the *BH* curve for the particular core material in ques-

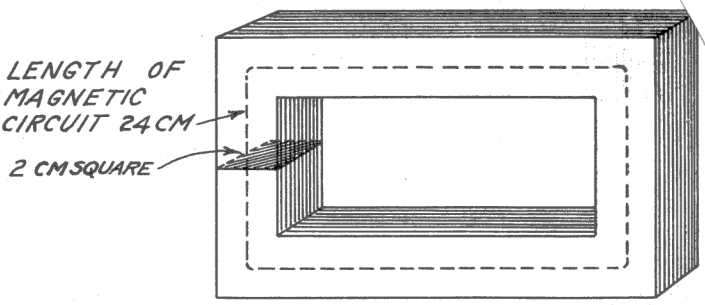


FIG 8

tion. These *BH* curves may be obtained from the manufacturers who make this material. The reluctance is equal to $R = \frac{H}{B}$

Here R equals reluctance, H is equal to Gilberts per *centimeter of length* of the magnetic circuit and B equals the flux density or units of Gausses. A more practical formula is $R = \frac{L}{Mu\ A}$ where L equals the length of the magnetic circuit in centimeters, Mu equals the permeability of the core material at a particular flux density and A equals the cross section area of the core in square centimeters. For example, as in Fig. 8, a power transformer core is shown using electric steel, in which the cross section area is 4 square centimeters. The length of the magnetic circuit as shown by the dotted lines, is about 24 centimeters. Suppose the power requirements are such that a flux density of 13.5 kilogausses at 10 Gilberts per centimeter are needed. Referring to the *BH* curve of Fig. 6, it may be seen that on the curve for electric steel, 13.5 kilogausses and 10 Gilberts are exactly on the knee of the curve. Using the formula

$R = \frac{L}{Mu\ A}$, $(Mu = \frac{13{,}500}{10} = 1350)$

then the problem becomes

$$R = \frac{24}{1350 \times 4} = .004 \text{ Oersteds}$$

—a low value, indeed, which, of course, is what is wanted.

HYSTERESIS

Hysteresis is a very important factor in A.C. operated magnetic circuits. It is analogous to the fly wheel action of inductance. Hysteresis is *magnetic inertia.* You will remember that once an EMF is started through an inductance, the current will tend to surge forward momentarily if the circuit is opened suddenly. The same effect applies to the flow of flux in a magnetic circuit. Due to the fact that once magnetism is started it is hard to stop or it tends to oppose any change, the flux density *B lags* behind the magnetizing force *H* because of this inertia or hysteresis of the magnetic circuit. This is graphically illustrated in Figs. 9 and 10. The curve marked *H* in Fig. 9 represents the wave form of the A.C. which causes the magnetism; in fact, it represents the magnetizing force *H* itself because these two forces are exactly in phase.

This is not true of the flux den-

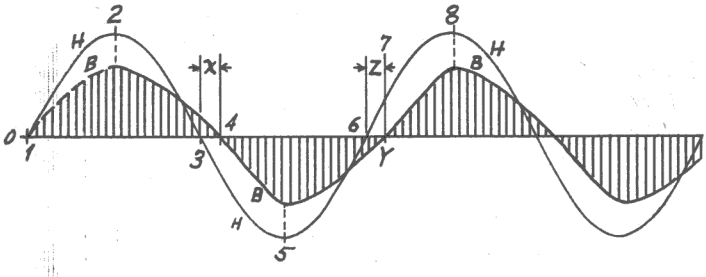


FIG. 9

sity B as this *lags* behind the magnetomotive force. Simply stated, B lags H. Curve B, of Fig. 9, represents the time relation between the flux density and the magnetomotive force changes. Note that both H and B start at point 1 and continue to the right in relation to time. At point 2 they are still in phase. When curve H reaches point 2, it is at its maximum value in a positive direction, and it begins to decrease toward point 3 to complete the half cycle. Curve B, however, does not reach zero or the base line until sometime later. The actual time difference is represented by the space X. The reason for this is due to the hysteresis or the inertia of the flux density. It tries to oppose a change in the magnetomotive force, and in so doing it tends to continue its action even after the source H has been removed.

Actually at point 3, H is not removed but continues on to point 5, Fig. 9, which is the maximum value in the negative direction. Between points 3 and 5 a different action occurs. Note that by the time the H curve reaches maximum, the B curve has again caught up with it, and they are again in phase. The H curve reaches zero at point 6, but the B curve does not reach zero until point Y, and by this time the curve H has advanced to point 7. Thus the two curves are out of phase by the time indicated at Z. By the time the H curve has reached point 8, the B curve has caught up and is again in phase. By carefully reviewing the two curves, it may be seen that for two periods of time, B and H, are out of phase except when the current is first turned on, and this action will continue as outlined.

The graph shown in Fig. 10 illustrates the same action as in Fig. 9 but in a different form. In Fig. 10, the values for H are plotted along the horizontal or X axis, and the values of B are plotted along the vertical or Y axis. Note that all four quadrants of the graph are used. The complete action represents one and one-quarter cycles corresponding to the points between 1 and 8 in Fig. 9. If it were not for the in-phase action be-

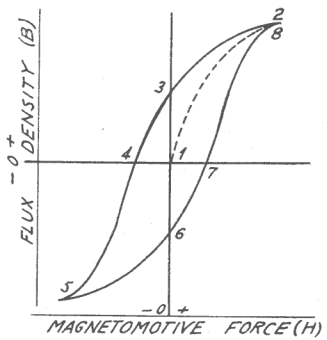


FIG. 10

tween 1 and 2 at the start, the dotted line could be eliminated and only one cycle would be shown.

It is important to realize in Fig. 10 that the curve represents neither *H* nor *B* alone. This curve shows the relationship between the two. For instance, the in-phase action of *B* and *H* at the start is indicated by the dotted line of Fig. 10. At the point 2 both start to decrease but get out of phase at point 3; *H* is zero, but *B* is still at some positive value. At point 4, *B* is zero and *H* is at a negative value corresponding to an increase in the negative direction as shown between points 3 and 5 of Fig. 9. Following this action will enable you to compare the two graphs.

The curve shown in Fig. 10 is called a hysteresis loop and has a real value in radio design where magnetic structures are used. Design engineers strive to reduce the loop area to a minimum. An ideal condition would be for both sides of the curve to come together so that only one line or curve would show. Such an ideal condition has never been attained in practice. The smaller the distance between 4 and 7 in Fig. 10, the less the hysteresis loss and the better the magnetic circuit. If there is a wide space between 4 and 7, there will be too much hysteresis loss and the transformer will function poorly.

When a core of a transformer is magnetized, the electrons and atoms of the core material line up, as you have learned, in one direction. This is true even though A.C. is used as the magnetizing force. When one-half cycle of A.C. reduces to zero as at point 3 of Fig. 9, the electrons and atoms of the core material are left lined up and affected by the magnetism for a period of time represented by point X in Fig. 9. This is what causes the flux to lag the magnetomotive force. This magnetism left in the core material after *H* has reduced to zero is called the *residual magnetism*. It is possible to magnetize an iron nail by wrapping it with a few turns of wire and causing a current, such as from a storage battery, to flow through the wire. This will be residual magnetism and is the same as the residual magnetism left in the core material described in Figs. 9 and 10. The only difference being that the magnetism left by one-half cycle is partially overcome by the next half cycle. This ability to retain some residual magentism is called the *retentivity* of the material.

At points in the curves of Figs. 9 and 10 where *residual magnetism* is present, it requires *energy* from the magnetomotive *source* to overcome it. This energy is dissipated as *heat* in the core material. This waste of heat is the *hysteresis* loss and must be kept to a minimum for efficient transformer operation. It is held to a minimum by choosing the correct *size of material.*

MAGNETIC SATURATION

A given size and kind of core material will only produce up to so many lines of force—regardless of the amount of magnetomotive power supplied above this critical point. A study of the *BH* curves in Fig. 6 will make this clear. Note that each of these four curves have sharp bends. At about 12.5 kilogausses, the carbon steel curve

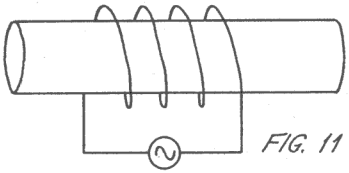


FIG. 11

shows near saturation while the curve for iron shows near saturation at about 17 kilogausses. The flux density may be *slightly* increased beyond this saturation point but *good engineering* practice is to design the whole transformer so that it is *always worked under this point.*

If this is done, the heat loss (due to saturation) is reduced and the transformer will operate more efficiently. It will also affect the output to a very large extent, as you may realize; due to the enormous lag created by oversaturation, the lines of force penetrating the secondaries would be so reduced that a very low output would result. This will affect *regulation,* and this will be taken up later in this lesson.

EDDY CURRENT LOSSES

There are other types of metal core losses. The first of these is the loss caused in the core material itself. Consider the simpler bar type core shown in Fig. 11. This could be an ordinary 20 penny iron nail. Actually, the core constitutes a shorted *one turn secondary* which means that there will be power induced in it and lost in the form of heat. The induced voltage sets up currents in the core which are, in this case, circular, as shown in Fig. 12. Since this core has a low resistance, these currents may be very large in value. Because these currents are present, a large magnetic field will exist. This field will oppose the field of the coil because an induced voltage is always opposite in polarity to the inducing voltage. Because of this opposition, more power would be drawn and more heat generated. Thus, this loss must be avoided as far as possible. From this, you will realize that *the use of a solid core is to be avoided.*

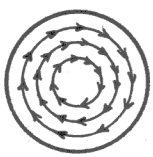


FIG. 12

This problem of *eddy current loss* is overcome by using thin sheets of core material. These thin sheeets are oxidized or sprayed with insulation so that when they are placed together they are prevented from making *electrical* contact with each other. These are called *laminations* and are usually from .010 to .015 inch thick. Many of these provide a large core area, but, by their use, the total electrical resistance is increased several hundred times thus providing a core which will, to a large extent, reduce the heat and loss caused by eddy currents. When these are stacked for assembly, they are usually clamped together and bolted. The bolt holes are made large and insulation used so as to prevent the bolts from creating other current absorbing paths.

TOTAL IRON LOSS

The total iron loss caused by hysteresis and eddy currents may be measured by the use of simple testing meters *providing* the electrical resistance of the primary is

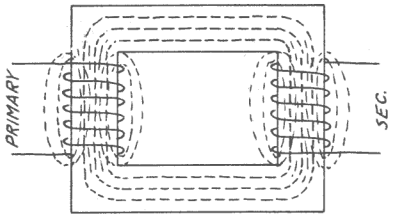


FIG. 13

obtained. The primary is then connected to a proper source of power with a sensitive wattmeter in the primary circuit. *All secondary windings* must be open and unloaded. The amount of power drawn will equal the *total core* loss *plus* the copper loss. The copper loss is equal to the *primary current squared* times the primary resistance. By subtracting this copper loss from the total power drawn, the total iron loss may be obtained. Added to these core losses and the total power must be the loss due to power factor to be explained later in this lesson.

FLUX LEAKAGE

Any wire or coil carrying current produces lines of force in all directions. It is practically impossible to confine all of the flux in a metal core. As may be seen from Fig. 13, some of the flux travels through air of the surrounding insulation. This small amount of flux acts like an inductive reactance. Its effect is to cancel part of the primary current due to the fact that each coil, of a transformer, carrying current induces a current not only into the secondaries but back into the primary as well. As you remember, this induced voltage is always opposite to the inducing voltage, and its effect is to reduce the primary current which, in turn, means that the sec-

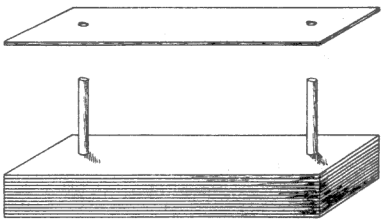


FIG. 14

ondary current will also be reduced. This is a problem of *regulation*. If the leakage flux is not limited or controlled it may affect the secondary voltages so as to make them unsuitable for use.

The self-induced voltage is called *counter EMF*. Its effect is the same as connecting an inductive reactance in series with the primary thus reducing the current flow in the primary. The leakage flux is very difficult to measure. However the design engineer must consider its effect and will usually allow a large enough lee-way in his calculations—this he will base on previous experience.

If the reluctance of the magnetic circuit should increase, the leakage flux will also increase. This is because the lines of force are constantly seeking the path having the greatest permeability. All substances *including* air *are con-*

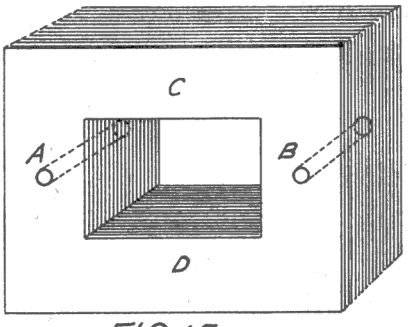


FIG. 15

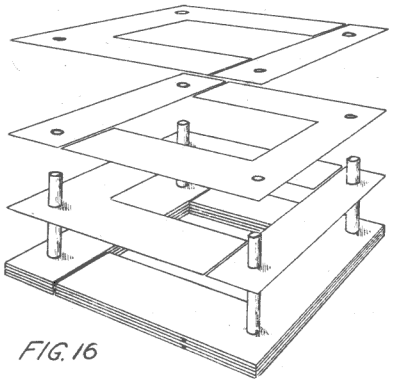


FIG. 16

ductors of magnetic lines of force. Some are better than others, but if the core's reluctance should increase it might be more than that offered by the surrounding air thus increasing the total flux leakage.

TRANSFORMER CORE CONSTRUCTION

The metal core of a transformer is usually made up of thin sheets magnetic metal. After being rolled to a suitable thickness, the sheets are punched out with heavy machinery to the required shape and size with any necessary holes. These *laminations* are then insulated after being freed of any burrs or slivers.

There are three general types of core construction.

1. The *open core* type is shown in Fig. 14. After being stacked they may be bolted or clamped together tightly. Open core types are more often made of a bundle of iron wires cut to the required length and insulated.

2. The *closed core* type is shown in assembled form in Fig. 15 and unassembled in Fig. 16. It would be difficult to wind wire on an assembled core so the laminations are usually divided and so stacked that each joint is covered by the adjacent laminations. By use of this method, it is possible to assemble the core into the made-up windings. The windings may all be placed on one leg of the core such as A, B, C or D of Fig. 15. The primary may be placed on one leg with the secondary windings on one or more of the other legs.

A recently developed core of the closed type is now used extensively in modern *Radar* equipment. It is made by rolling two complete halves. By rolling the lamination stock into tissue thin strips and forming a group of them into a U shape, much thinner laminations may be used. These are handled after being formed, as a single solid half core would be. The two halves are bound into coils by a single turn of steel tape which is clamped and sealed.

3. The *shell core* type is illustrated in Fig. 17. This is the most efficient type and probably the most widely used.

You will note that there are three legs on this type and the windings are generally placed on the center leg, one winding over the other. The primary is usually wound first on the core so as to insure the maximum transfer of energy into the core.

As may be seen in Fig. 17, three magnetic paths in parallel are used. This reduces the reluctance and in-

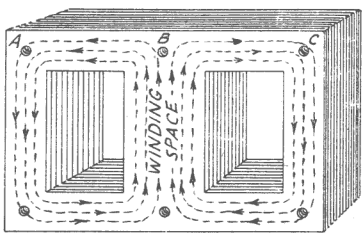


FIG. 17

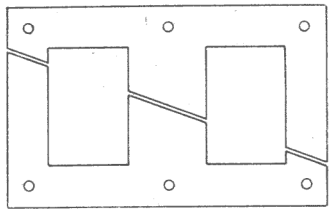


FIG. 18

creases the permeability much more than in a series magnetic circuit such as Fig. 15. The dotted lines in Fig. 17 show the path of the flux. The laminations for this type of core are shown in Fig. 18. Note the E shape of each half lamination; because of this, this type is called an E lamination. The cost of the extra material in this type of lamination is offset because only one type of puching die is needed. These are also stacked in alternate directions so that each joint is covered by the laminations adjacent. They are split to permit their assembly into the prepared coil.

TRANSFORMER CORE CHOICE

You have learned how the amount of flux is related to the turns ratio and this will govern the size of a core to some extent. There are other important considerations governing the choice of core design. One of the first considerations is the size and insulation of the wire. This is because a certain number of ampere-turns would be necessary, and it might not be possible to wind the required number of turns into the space provided by the dimensions of the core. There is usually more than one winding, in which case, more space would be required.

In order to solve the foregoing problem, reference to tables similar to the following is necessary:

1. Safe current carrying capacity of wire (inclosed windings).
2. Turns per inch.
3. Insulation thickness for various voltages.

The next consideration involves the size of the form to be used, including the end pieces.

Another important point in choosing a core would be the frequency for which it is to be used. A core for 25 cycle A.C. will be almost twice as large in cross section as a core designed for 60 cycles. As the two are not safely interchangable, this point must not be overlooked.

American design practice has adopted the ratio of watts to core area of *about* 40 watts per square inch of core *area*.

Here a word of warning. Due to the change in impedance brought about by a change in frequency, a very heavy current will flow when a 60 cycle transformer is used on a 25 cycle power line. Because of this fact, the transformer will overheat and its wire windings may burn out.

A 25 cycle transformer will operate on 60 cycle current but will be inefficient due to the lag in the core, and, as impedance changes with frequency, the voltage and current values will be incorrect. You will study later why other components of power supply units may not function on incorrect operating frequencies.

When calculating the space which core material is to occupy, a 10% allowance must be made in the direction in which the laminations are stacked. This is because of the insulation of the lamina-

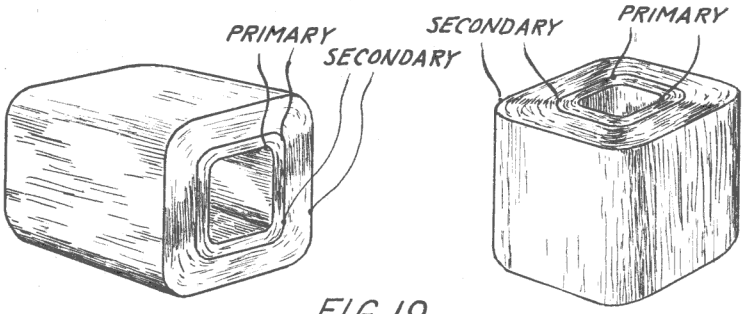


FIG. 19

tions and the variation in flatness, air space, etc.

Other factors influencing the choice of a core besides its area and material would be the type or shape of lamination punching available. The impregnation, type of terminal support, method of clamping and manner of shielding and mounting all require study before a final choice is made.

TRANSFORMER COIL CONSTRUCTION

Coils today are mostly machine wound. A collapsible mandrel sometimes large enough to hold several coil *forms* is used. This revolves in a machine which automatically feeds the wire. A layer of wire is wound on the form, then a layer of insulating paper or cloth, then another layer of wire with another layer of insulation. Alternate layers of wire and insulation are thus built up around the outside of the coil and usually acts as a binder for the ends of the coils. This is necessary to prevent strains from unwinding the turns of wire. The collapsible mandrel is then removed, leaving the coil wound on its insulation form ready to receive the core. A completed winding is shown in Fig. 19. This is an illustration of a typical coil. In practice, the different windings may be placed inside or outside of the position shown. Figure 20 shows the mounted and completed transformer.

A very important point is the type of insulation. Requirements of the trade have indicated that what is known as plus insulation should be used. This means that *all* insulation shall be able to stand

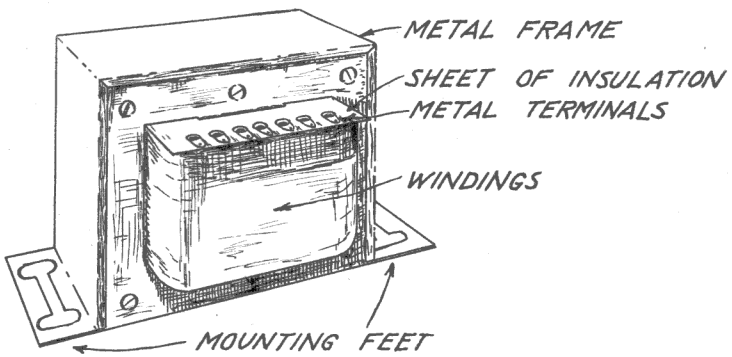


FIG. 20

at least twice the total added voltage of all windings. Thus, for a typical case, a transformer wound to furnish 6.3 + 6.3 + 5 + 750 volts from a 120 volt source would use insulation capable of *withstanding 1775 volts A.C.* In many cases such as special filament transformers for transmitters, the insulation must be much better as it will have to withstand the peak plate current of the tubes.

Another problem is the question of structural support for the windings. There is a definite magnetic pull tending to move the turns. If the windings are not solidly supported and tightly wound, this force will ruin the transformer. If the turns are too tightly wound, one or more could *cut through* the insulation so it is important that the insulation chosen be substantial enough to handle this pressure. Then, too, the insulation of the *form* as well as other insulation used towards the inside of the winding must withstand the *total added* pressure of all the turns outside its layer.

After the coil is wound, it is usually impregnated with a moisture resisting insulation. This is accomplished by submerging the coil in this impregnating compound and subjecting the whole to heat and vacuum. This will remove moisture and air from the winding. When all bubbles stop, the vacuum is released and air pressure will drive the compound into all crevasses and voids of the coil. It is then freed of all excess compound and assembled.

Practically all wire used in transformers is insulated. There are several types of wire insulation used. Typical examples are:

Enamel
Cotton Covered
Silk Covered
Glass Covered
Rubber Covered

Enamel wire is the most widely used. The thickness of the coating varies according to the size of the wire, but it will run from about 1.5 mil. ($\frac{1}{1000}$ inch) to about 3.5 mils. Even on small wire, the enamel coating will withstand over 1000 volts. The enamel used is of high dielectric strength and very flexible. Enameled wire is usually less costly than other types of insulation.

Cotton covered wire is wound, as the name implies, with either one or two layers of cotton thread. The single layer is termed S.C.C. and the double layer is called D.C.C. Cotton or silk covered wire should not be used in windings which are subject to moisture. The thickness of the covering varies from 0.5 mil. to 8 mils. Silk covering runs about the same in thickness as cotton and is termed S.S.C. or D.S.C.

A most popular wire covering is a recent development that has enabled the use of spun or woven glass fibers of very small diameter. This is a war-time development and will withstand rough handling, high heat and is so woven as to possess a good dielectric strength. Most all modern transmitters and receivers make use of glass insulated wires. The thickness is comparable to the other insulations mentioned.

WIRE SIZES

Wire for use in transformers must be chosen large enough to carry the current its winding is to supply without an appreciable heat rise.

A wire size is usually chosen large enough to handle a 100% overload. It must be of a shape and diameter so as to get the most *turns per inch.* And the insulation should be chosen to withstand the pressure of other windings, as mentioned before, yet be flexible enough to safely withstand whatever bends it must follow. Wire shape is generally round though sometimes it is rectangular or often square so as to more completely occupy the winding space.

Economy in a transformer is secured when the winding incloses a *maximum* of core area with a minimum of wire on as short a magnetic circuit as possible.

A list of wire sizes, those most used in radio work, is shown in your SAR lesson ND1. Here the outside total diameter, not including insulation, is given. In other columns is shown the number of turns per inch that can be wound tightly. The next column gives the allowable current capacity.

The wire size is determined by the number of *circular mils per ampere* (usually written cmpa) it is desired to use. A safe rule is to use 1000 cmpa. for transformers under 50 watts and 1500 cmpa. for units handling higher power values.

In calculating the space for a winding, a space at each end of the form must be left unwound as shown in Fig. 21. This space will increase as the layers increase to

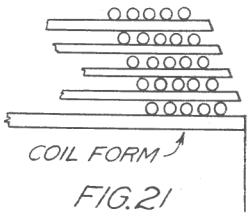


FIG. 21

prevent the last turns from sliding off the ends.

This will decrease the number of turns to be included in the space. Figure 21 is exagerated to show more clearly the method. Practice shows a loss of only about one turn per layer.

Although it is not necessary to allow for insulation when winding one layer, each additional layer requires a thickness of insulation which will occupy part of the space of the coil's diameter. This must be taken into account.

The importance of this may be illustrated by the fact that, while 900 turns of enamel wire *without insulation* may be wound in a space one inch square, only 600 turns *with insulation* could be wound in the same space. If cotton covered wire were used, only 400 turns could be wound in one square inch space. Reference to the wire table supplied by its manufacturer will aid in calculating the space to be occupied.

Due to the fact that there is less chance for heat removal by circulation in the inside of a winding, it is a good policy to figure a wire one size larger for the inside windings than for the outer windings *for equal currents.*

An inside winding will have a smaller circumference than an outside winding. Thus a longer length of wire will be required for the outside windings. This makes,

if the same number of turns are used on each of two windings, a *larger* I^2R drop occur in the outer winding because of the longer wire length. Slightly *less* flux will pass through the outer winding, also causing a loss.

COPPER LOSS

Some loss will occur in a transformer due to the I^2R loss in the windings and leads. This may be computed for each winding by first obtaining the average length of a turn. Multiply this by the length and by the resistance per foot. This result, times the current squared (of that winding) will equal the copper loss for that particular winding. The addition of the losses of all the windings will give the amount of total copper loss. This last mentioned loss is adjusted by *adding additional turns* to the outer winding.

This is especially necessary when, for instance, the winding is a centertapped high voltage winding to supply a full wave rectifier. It may be seen that if the *electrical center* of the winding were used each rectified impulse would be equal. If the *turn center* were used one half cycle would reach a higher voltage than the opposite. This will introduce a hum into the filter which is more expensive to remove.

For this reason, most engineers specify that centertaps be made from the electrical center of the windings and that compensating turns be added when necessary.

It is often desirable to identify the windings of an unknown power transformer. The *largest size wire* leads will, as a rule, be those supplying the filament or heater current for the tubes of the receiver. The next largest will usually be the rectifier filament supply. The next smaller wires may supply the primary and usually the smallest or most flexible wires supply the *high voltage. Do not attempt to connect the transformer unless you are certain that the proper windings are identified. A very high voltage, dangerous to life and property,* can result from an improper connection. In this connection, you should *always* keep clear of any high voltage windings. Don't touch high voltage windings while the *primary* is connected to the power line.

One good method of identifying a winding would be by the use of an ohmmeter—the highest resistance being the highest voltage and so on.

If the leads of an unknown transformer use various colors, it may possibly be arranged according to the RMA color code for transformers which is shown in Fig. 22.

TRANSFORMER REGULATION

Now that you are acquainted with transformer operation, you will, no doubt, be interested to learn how this useful piece of equipment can be made more efficient.

If a transformer is operated at its *maximum* power and if the load varies, certain conditions exist which cause the output power to change a great deal more than is at first apparent.

A transformer so designed as to correct most normal *load demand variations* is said to be well regulated. One which does not

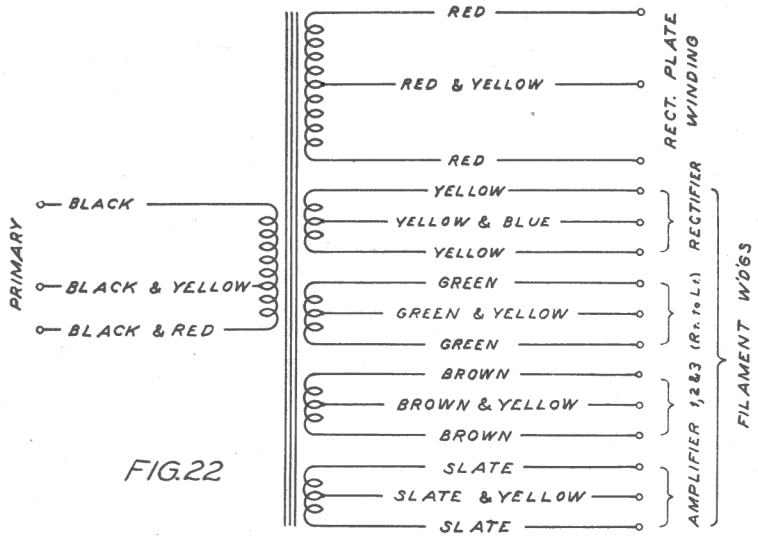


FIG.22

correct these load demand variations is said to be poorly regulated. Regulation is expressed in the percentage of change of the *open circuit secondary voltage* which occurs when the load is applied with a specific power factor and with a constantly maintained primary voltage.

Due to the inductance of the primary (it has resistance) the current in the primary will always lag the voltage. This is true because, as you know, in order for a current to flow there must first be a voltage or pressure. The voltage in the supply line is always varying at the same rate, but because of the inductance of the primary and its *inertia* effect, the current must lag the voltage. Now the resistance of the primary is not sufficient alone to prevent an abnormal current from flowing. If the inductance was removed, the primary would be destroyed because its resistance is not high enough to limit the current flow to a safe value.

You have learned that almost all the lines of force created by the primary *cut* through the secondary, thus inducing a voltage in the secondary. This induced voltage in the secondary is 180° out of phase with the inducing lines of force.

The amount of this applied magnetomotive force can only be equal to the *actual power supplied from the power line* because this actual power must come from the line when the voltage and current are in phase.

If the secondary is open and unloaded, there are only the losses of the core to absorb power. The primary then *increases* in inductance because of the high flux present in the core. Because its inductance is increased, its inertia effect is increased causing less current to flow. In fact, in a good transformer only about 4% of the power is lost.

If a load is now applied to the secondary, the voltage induced in

it will force a current through the load. But, by absorbing the major portion of the lines of force, the secondary has the effect of *lowering* the inductance of the primary. This is because the core's reluctance is reduced thereby aiding in this transfer of energy. Because the inductance of the primary is reduced, more current will flow through it due to the weakening of its inertia effect.

Certain of these facts also apply to the secondary because when current is passing through, its inductance will be reduced.

If you now *short circuit* the secondary, it will possess practically no inductance and possesses only its small quantity of resistance, thus allowing a large current to flow. This, in turn, absorbs most of the lines of force which leaves the core in a permeized condition. Having thus lost its support of inductance, the primary is left possessing only resistance which allows a damaging current to flow, and if no fuse is provided, it will burn out.

It is not possible to design an ordinary transformer to hold a constant secondary voltage with a varying load demand. However, if the limits of the demand are known, it is practical to design a transformer which will, to a large extent, control or *regulate*, the electromagnetic conditions within itself so as to compensate for these load variations. This involves the use of very carful judgment when designing the unit, as you have learned. By choosing a value of mutual inductance which will be least affected by these load demands, regulation can be improved. As you may readily see, this will require more than merely selecting a volts-per-turn ratio on a core of sufficient size.

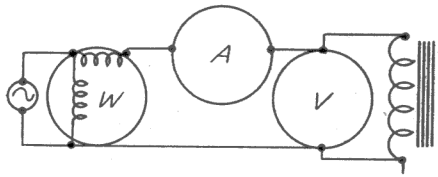


FIG.23

POWER FACTOR

Power factor is the ratio of the *apparent power* to the *actual power*.

A simple way of measuring these two quantities is by the use of a wattmeter, a voltmeter and an ammeter. The circuit set up for such a case is shown in Fig. 23. The product of the readings of the voltmeter and ammeter will give the apparent power while the reading of the wattmeter will give the true power.

When the alternating current and voltage are truly sinusoidal (perfect wave form), power factor is expressed as being equal to the *cosine of the angle* which expresses their *difference* in *phase* as shown in Fig. 24.

When alternating voltage and current are exactly in phase (which is seldom the case) the power factor would be 1.0 or unity. Power factor is usually expressed in percentage; thus, if the product of the readings of the voltmeter and ammeter in Fig. 23 were multiplied by the power factor, the re-

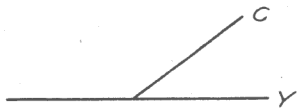


FIG.24

sult would equal the true power as shown by the wattmeter.

THE IMPORTANCE OF POWER FACTOR

Power Factor in the past has been overlooked by many radio men. Its importance may be illustrated by the following example.

A power unit is desired for use with a radio receiver amplifier. The calculated load demand limits, with a constant line voltage, are low power 90 watts, medium, 95, full power 100 watts.

If the power factor at the supply line terminals to the transformer is 90% then only 90% of the apparent power, as represented by voltage times amperes, can be delivered by the transformer if it were perfect with no loss. At high volume then only 90 watts is available. Removing the loss in the transformer plus its power factor, will leave even less power available.

In your SAR lessons you have already studied the effects of voltage-current-phase actions. Because all pairs of wire offer both impedance and capacity, the power lines may affect the power factor in many locations. The fact that other appliances are used on the line such as neon transformers and capacity operated motors may alter the power factor a great deal. Automatic power factor correction devices are in use by power companies but these, as a rule, are applied only to main high voltage transmission lines. Thus, the power factor of the source to be used always plays a large part in the efficiency of a power transformer.

The calculated value of voltage and ampereage in the primary will be larger than the actual value because of the power factor.

The loads on a transformer secondary are nearly unity in *Power Factor.*

ASSOCIATED TRANSFORMER VOLTAGE REGULATORS

Knowing that line voltages do not remain constant, some manufacturers include *automatic compensators* or voltage *regulators* in the primary circuit of the transformer.

A good example of the *ballast* type is shown in Fig. 1 as resistor R.

To explain its action, you will recall that most materials possess a *positive* temperature-*resistance* coefficient. In other words, as their temperature rises, their resistance increases. If this were not true, an ordinary electric iron or electric light would keep on increasing in temperature and burn out. However, due to this coefficient as the temperature increases, the resistance goes up to the point where the power input equals the heat radiated and a state of equilibrium exists.

Suppose the transformer in Fig. 1 was wound to obtain its power at a voltage of 85 volts. The resistor R would be chosen in value (ohms) so as to produce a drop of 25 volts *at a certain temperature.* As the transformer primary and the resistor are in series, the total applied voltage should equal 110. If now the supply voltage were to increase, say to 120 volts, more current would pass. This would increase the temperature of R (Fig. 1) which would increase its resistance. This increase in

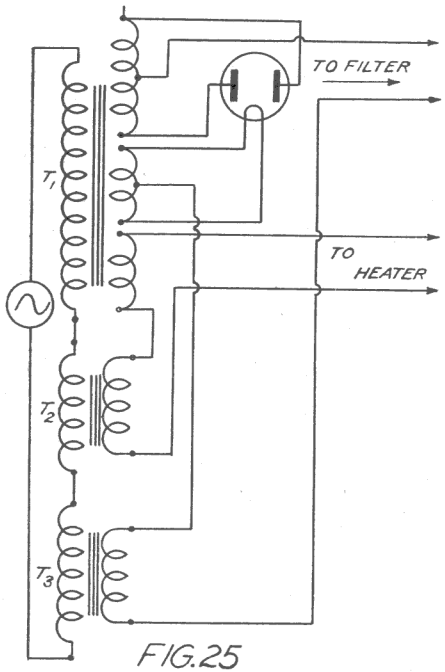


FIG. 25

resistance would then increase the *voltage drop* asross the resistance R, and if properly chosen in relation to the primary would hold the voltage across the primary to 85 volts. If the voltage of the supply line were to reduce, the opposite action would occur, and the transformer would still operate from the normal voltage.

These *ballast* resistors take many different forms. Some are woven into the power supply cable of the receiver as is the case with most small A.C.-D.C. receivers. Others are built into regular tube envelopes, either metal or glass. Others are wound on heat proof supports and exposed to ventilation to improve the heat dissapation, thus increasing the rapidity of their action.

Among the most recent improvements in regulating systems is that shown in Fig. 25 and makes use of the saturation of the two transformers T2 and T3. As may be seen, the promaries of T_1, T_2 and T_3 are in series. T_1 is the main power supply transformer, while T_2 and T_3 act to regulate the power flowing through T_1 because they act as variable reactances in the following manner.

The secondary of T_2 is in series with the main rectifier load. As the current, drawn by the rectifier, varies due to *either line voltage* variations or load demands, it will increase or decrease the current through the secondary of T_2. As you have learned in this lesson, due to *mutual* inductance, the current in a transformer secondary may be made to alter the actual resistance of the primary because the interaction between the two windings changes the inductance of the primary. For this reason, T_2 will, if properly adjusted, *control* and *compensate* for line or load demand variations. T_3 is so arranged in series with the filament or heater supply as to accomplish the same result as explained for T_2. These three transformers must be designed to work with each other on a certain application. For this reason the manufacturers generally supply them in one case, although in large installations they will be separate.

AUTO TRANSFORMERS

So far consideration has been given the type of transformer having *separate* primary and secondary windings. Separate windings are not always necessary. Figure 26 shows the auto transformer wherein one winding acts as both primary and secondary.

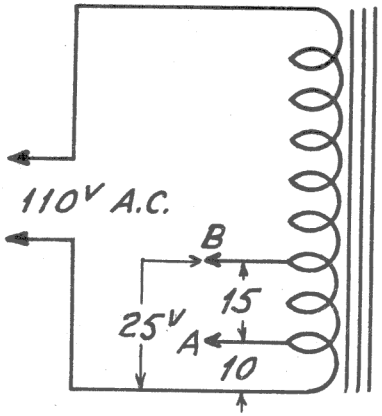


FIG. 26

This type of transformer acts on the same principle as one having two or more windings. The taps or connections at the various turns determine the ratio between windings. For instance, in Fig. 26 the complete winding may be considered as the primary. The windings between the low voltage taps may be considered as the secondaries. Thus, two taps—A and B —give 10 and 25 volts respectively.

From a study of this circuit, you can see that the auto transformer acts somewhat like a potentiometer of the resistance type which is connected across a voltage source. Different points along both give different voltage values. In the auto transformer the same ratio holds true as for a transformer having separate windings.

That is, $\frac{Ep}{Np} = \frac{Es}{Ns}$

The circuit of Fig. 26 shows a step-down auto transformer. Figure 27 shows a step-up auto transformer. In this case, 110 volts are applied to terminals A and B. By arranging the proper number of turns between A and C, 300 volts of A.C. are obtained from the same winding. If 250 turns are included between A and B (the primary), and 300 volts is wanted across B and C (the secondary), then the number of secondary turns may be calculated by using the *volt-per-turn* formula. The volts per turn in this case is equal to $\frac{250}{110} = 2.27$.

The number of secondary turns then is equal to $300 \times 2.27 = 681$ turns. There are 250 turns in the primary so the actual number of turns needed between A and C to give 300 volts is $681 - 250 = 431$ turns.

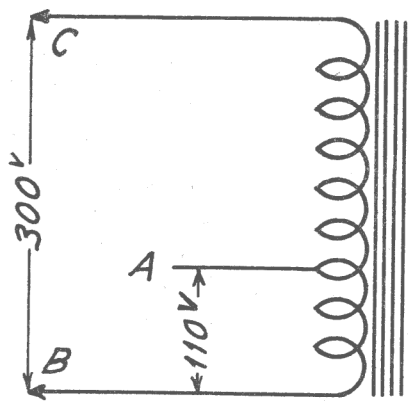
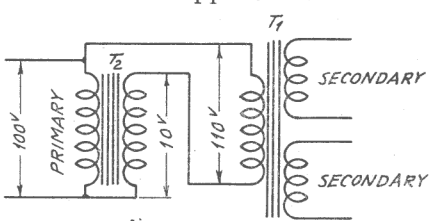


FIG. 27

The auto transformer principle is often made use of in localities where the line voltage is *consistently low*. Figure 28 shows the connection. Suppose the line volt-



SEC. FIG. 28

age is 100 volts, and it is desired to increase it to 110 volts before it is applied to the primary of the regular power transformer (see T1 of Fig. 28). To increase the line voltage to 110 volts, all that is necessary is to connect a 10 volt step-down transformer as an auto transformer. This is done by connecting one side of the secondary to one side of the primary so as to make one continuous winding. The primary of the auto transformer is then connected to the line as shown. The 10 volts appearing at the secondary of this transformer *adds to the line voltage.* This means that 110 volts is applied to the primary of the transformer T1. Thus the line voltage is increased from 100 volts to 110 volts. The same principle holds true for other low values of line voltage. Likewise, an A.C. 220 volt line may be reduced to 110 volts or to some other lower value by using a step-down auto transformer. The same object is usually accomplished in many modern radio sets by using a *tapped primary* as in Fig. 1. This as you will note is one form of an auto transformer.

The auto transformer principle is also made use of in audio amplifying circuits where it is desired to couple the plate of one tube to the grid of the following tube. This was explained in your lessons on audio amplification.

These questions are desigend to test your knowledge of this lesson. Read them over first to see if you can answer them. If you feel confident that you can, then write out your answers, numbering them to correspond to the questions. If you are not confident that you can answer the questions, re-study the lesson one or more times before writing out your answers. Be sure to answer every question, for if you fail to answer a question, it will reduce your grade on this lesson. When all questions have been answered, mail them to us for grading.

QUESTIONS

No. 1. Explain how transformer secondaries can supply both a higher and a lower voltage than the primary.

No. 2. In a given magnetic metal, what two things determine the amount of magnetism that it can carry due to a fixed number of ampere-turns?

No. 3. What is the natural opposition of a magnetic metal to CHANGES IN MAGNETIC FLUX called?

No. 4. What is meant by residual magnetism?

No. 5. Why are transformer cores laminated?

No. 6. What name describes the condition of a transformer when the magneto-motive force is so high that a further increase of it will not increase the magnetic flux?

No. 7. What is the difference between an auto transformer and an ordinary transformer?

No. 8. What is the difference between a closed core transformer and a shell core transformer?

No. 9. Explain how an additional transformer may be used to compensate for low line voltage.

No. 10. Why is each laminated layer of a transformer core made in two pieces instead of one?